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A Review of Biophysical Differences Between Aquatic and Land-Based Exercise

W. Matt Denning, Eadric Bressel, Dennis Dolny, Megan Bressel, and Matthew K. Seeley

Four of the most popular modes of aquatic exercise are deep water (DW) exercise, shallow water (SW) exercise, water calisthenics (WC), and underwater treadmill (UT) exercise. The mechanical requirements of each aquatic exercise mode may elicit different physiological and biomechanical responses. The purpose of this descriptive literature review was to evaluate some biophysical differences between aquatic and land-based exercises. The biophysical variables reviewed included oxygen consumption (VO_2), heart rate (HR), rating of perceived exertion (RPE), stride length, stride frequency, pain, and measures of functional gain. Based on the studies reviewed, when compared with similar land-based exercises, VO_2 and HR maximum values were lower during DW and SW exercise, but, depending on water depth and exercise performed, may be greater during WC and UT exercise. RPE during DW exercise was generally similar to land exercise during max effort. Stride frequency tended to be lower for all four aquatic exercises, relative to on-land counterparts. Pain levels tended to be similar between WC and land exercise, yet may decrease after UT exercise.

Keywords: rehabilitation, hydrotherapy, aquatic exercise, kinematics, joint pain

The popularity of aquatic exercise is increasing for various reasons, including increased accessibility of pool facilities and improved understanding of health-related benefits; this increase in popularity is particularly true for special populations. Individuals who suffer from various orthopedic dysfunctions (e.g., arthritis) and have difficulty performing on-land exercise may benefit from aquatic exercise (Cassady & Nielsen, 1992). Aquatic physical therapy may facilitate ease of movement, swelling reduction, and pain relief due to the pressure and warmth of water (Hinman, Heywood, & Day, 2007). In addition, the effects of water resistance (i.e., drag forces) may increase energy expenditure (Gleim & Nicholas, 1989; Hall,

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Macdonald, Maddison, & O'Hare, 1998) and decrease mechanical loads on lower extremity joints (Barela & Duarte, 2008; Barela, Stolf, & Duarte, 2006).

It is important for rehabilitative clinicians to understand physiological and biomechanical responses (hereafter referred to as biophysical variables) that are related to aquatic exercise. Clinicians should also understand how the aforementioned responses may differ, relative to land-based exercise. Deep water (DW) and shallow water (SW) exercise, water calisthenics (WC), and underwater treadmill (UT) exercise are some of the most popular forms of aquatic exercise. The mechanical requirements of each aquatic exercise may elicit different physiological and biomechanical responses. For example, DW exercise does not include ground contact (Reilly, Dowzer, & Cable, 2003), while SW exercise, UT exercise, and WC do include a ground contact. This difference may partially explain why oxygen consumption (VO_2) is typically lower during DW running, relative to SW running (Town & Bradley, 1991). The mechanical requirements of each aquatic exercise also make it difficult for clinicians to know which aquatic exercise will achieve desired therapeutic goals. For instance, if the goal of the clinician is to prescribe an aquatic exercise that most closely mimics the oxygen consumption demands of land-based exercise, then an understanding of the physiological responses of each type of aquatic exercise is imperative. If the goal of the clinician is to prescribe an aquatic exercise that increases functionality while decreasing pain, then an understanding of the biomechanical and pain responses are equally important. Knowledge of different biophysical responses during aquatic exercise will help clinicians prescribe the most beneficial form of aquatic treatment for their patients.

The purpose of this paper was to provide a descriptive literature review of acute and chronic biophysical differences between aquatic and land-based exercise. The biophysical variables examined in our review included VO_2, heart rate (HR), rating of perceived exertion (RPE), stride length and stride frequency, pain level, and functional gains. The practical aim of this paper was to help clinicians better understand which exercise environment (i.e., land or water) may be most advantageous for their patients. Not all biophysical variables have been included in this review. For example, blood lactate, blood pressure, ground reaction forces, muscle electromyography, and joint kinematics were not included mainly because of limited data for comparisons between modes. In this paper, we reviewed (a) four modes of aquatic exercise, (b) physiological responses ($VO_{2,}$ HR, and RPE) for aquatic exercise compared with land-based counterparts, and (c) biomechanical and pain responses (i.e., stride frequency, stride length, pain, and functional gains) for aquatic exercise, relative to land-based exercise.

Method

To accomplish our stated purpose, searches were performed using several databases and search engines that included SPORTDiscus, Academic Search Premier, CINAHL, Google Scholar, PubMed, and a university library catalog. We chose to cite studies that involved the aforementioned biophysical variables (a) during and/or after aquatic and land-based exercise (walking or running with the exception of a few WC studies), (b) on young and elderly able-bodied subjects or young and elderly special populations, and (c) without the use of equipment (e.g., drag materials).

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Modes of Aquatic Exercise

Although there are many different modes of aquatic exercise and therapy, this descriptive literature review included only deep water (DW) exercise, shallow water (SW) exercise, water calisthenics (WC), and underwater treadmill (UT) exercise, as these modes are the four most commonly cited in the literature.

Deep water exercise is performed when individuals walk or run in the water with no contact with the pool floor. Typically, DW exercise involves minimal translation through the water (the participants stay in the same place). Flotation aids (e.g., a buoyancy vest or belt) are often used to suspend the participant, so that no ground contact occurs during the exercise (Reilly et al., 2003). Shallow water exercise is performed in a depth typically at the xiphoid level (Dowzer, Reilly, Cable, & Nevill, 1999), where participants may run or walk propelling themselves through the water (Gappmaier, Lake, Nelson, & Fisher, 2006). Participants are able to contact the pool floor, therefore, eliminating the need for flotation devices.

Water calisthenics are achieved by performing a variety of aerobic conditioning and resistance training exercises usually in the shallow end of a pool (Cassady & Nielsen, 1992). This mode of aquatic exercise includes any type of exercise except continuous walking and running. Underwater treadmill exercise uses a treadmill submerged in water (Gleim & Nicholas, 1989). Some underwater treadmills include adjustable water jets (Rutledge, Silvers, Browder, & Dolny, 2007). These jets allow the therapist to alter the horizontal forces of water resistance. In addition, some underwater treadmills permit the therapist to adjust water depth and regulate the vertical ground reaction forces that are applied to the participant by the treadmill. By systematically controlling the horizontal resistive forces and vertical ground reaction forces that are applied to the participants, a therapist can better control exercise intensity. This level of control is not found in other forms of aquatic exercise (Denning, Bressel, & Dolny, 2010).

Physiological Responses

Each mode of aquatic exercise results in different physiological responses. The studies reviewed in this section met the criteria for investigating VO_2, HR, or RPE during comparable aquatic and land-based modes.

Oxygen Consumption. Oxygen consumption is the product of cardiac output (stoke volume × heart rate) and arterial-venous oxygen difference (a-v O_2 diff), and is linearly related to caloric energy expenditure (see Table 1). Oxygen consumption is frequently used to indicate the level of aerobic intensity for a certain individual or activity (Johnson, Stromme, Adamczyk, & Tennoe, 1977). A comparison of VO_2 values allows for an objective comparison of intensity between modes of exercise.

DW Exercise. Researchers have indicated that maximum oxygen consumption (VO_{2max}) during DW exercise is lower than VO_{2max} values during over-ground treadmill running (Table 1). There is a large variability in results that range from a 10% decrease (Butts, Tucker, & Greening, 1991a; Frangolias & Rhodes, 1995) to a 27% decrease (Nakanishi, Kimura, & Yokoo, 1999b). Although some females obtained a VO_{2max} lower than males (Butts, Tucker, & Smith, 1991b), both genders display lower values in the water compared with land. This would indicate that gender is not a contributor to the lower VO_{2max} values during DW running exercise.

Table 1 Description of Studies Comparing RPE and VO_2 Responses During Different Aquatic Modes to a Similar Land-Based Mode

Study	Mode	Sample	Speed	Depth	Temp	RPE Outcome	VO_2 Outcome
(Butts et al., 1991a)	DWR	12 trained men and 12 trained women	Starting cadence of 100 beats/min increasing 20 beats/min every 2 min	Neck level	29 °C	Not measured	VO_{2max} was 16% lower in water for women and 10% lower in water for men.
(Butts et al., 1991b)	DWR	12 high school cross country females	Starting cadence of 100 beats/min increasing 20 beats/min every 2 min	Neck level	29 °C	No difference	Peak VO_2 values were 17% lower in response to DWR.
(Mercer & Jensen, 1997)	DWR	12 women and 14 men	1-min stages adding 0.57 kg each min to a bucket and pulley system	Neck level	27 °C	Not measured	Lower mean peak VO_2 values during DWR.
(Nakanishi, Kimura, & Yokoo, 1999a)	DWR	20 healthy nonsmoker males	48 cycles/min warm up for 4 min followed by 66 cycles/min increased by 3–4 cycles/min every 2 min	Not reported	32.5 °C	No difference at max effort	VO_{2max} values were approximately 20% lower in DWR when compared with land running.
(Nakanishi et al., 1999b)	DWR	14 young and 14 middle aged males	48 cycles/min warm up for 4 min followed by 66 cycles/min increased by 3–4 cycles/min every 2 min	Not reported	32.5 °C	No difference at max effort	Middle aged group was 27% lower during DWR, young group was 21% lower.
(Glass et al. 1995)	DWR	10 males and 10 females	Started at 80 strides/min and increased 120 strides/min until voluntary exhaustion	Neck level	Not reported	Not measured	VO_{2max} values were 11% lower during DWR.
(Matthews & Airey, 2001)	DWR	6 males and 4 females	60%, 70%, and 80% of heart rate reserve	Sterno-clavicular level	30 °C	Greater for each speed	

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Table 1 *(continued)*

Study	Mode	Sample	Speed	Depth	Temp	RPE Outcome	VO_2 Outcome
(Svedenhag & Seger, 1992)	DWR	10 trained male runners	Four submaximal loads and max exertion	Neck level	Not reported	Greater for each speed	VO_{2max} values were 14% lower during DWR.
(Chu et al., 2002)	DWR	9 young and 9 elderly females	Increase load each min to max exertion	Neck level	28 °C	Not measured	VO_{2max} values were lower during DWR for both groups.
(Dowzer et al., 1999)	DWR & SWR	15 trained male runners	DWR- 120 strides/min SWR- 132 strides/min	DWR- chin level SWR- waist level	29 °C	Not measured	Peak VO_2 averaged 83.7% and 75.3% of land treadmill running during SWR and DWR, respectively.
(Town & Bradley, 1991)	DWR & SWR	7 male and 2 female runners	Increased each min, final 2 min represented max exertion	DWR- 2.5–4m SWR—1.3m	Not reported	Not measured	VO_{2max} values were 90.3% and 73.5% during SWR and DWR, respectively.
(Takeshima et al. 1997)	SWR	18 elderly participants	Self-selected easy, moderate, and hard speeds	Axilla	30 °C	No difference	No difference at easy and moderate speeds yet lower at hard speeds.
(Johnson et al., 1977)	WC	4 men and 4 women	66 beats/ min and 58 beats/ min	Shoulder level	26–26.5 °C	Not measured	VO_2 values were greater during WC.
(Cassady & Nielsen, 1992)	WC	20 males and 20 females	Exercises performed at 60, 80, and 100 counts/ min	Shoulder level	29 °C	Not measured	VO_2 responses were greater during WC than exercises performed on land.
(Hoeger et al., 1995)	WC	19 males and 11 females	Cadence of 80, 88, 92, 100, and 108 beats/min	Armpit level	28 °C	Significantly lower	Peak VO_2 was approximately 15% lower.
(Darby & Yaekle, 2000)	WC	20 college-aged females	Cadence increased every 3 min according to heart rate.	Chest deep	30 °C	Not measured	VO_2 was approximately 2–6 $ml*kg^{-1}*min^{-1}$ greater.

(continued)

Table 1 *(continued)*

Study	Mode	Sample	Speed	Depth	Temp	RPE Outcome	VO_2 Outcome
(Barbosa et al., 2007)	WC	7 males and 9 females	"rocking horse" exercise at a music tempo of 136 beats/min	Both hips and xiphoid	29 °C	Significantly greater	VO_2 responses were lower during WC than exercises performed on land.
(Gleim & Nicholas, 1989)	UT	6 men and 5 women	Started at 0.67 m/s and increased 0.22 m/s every 2 min	Ankle, knee, midthigh, and waist deep	30.5 and 36.1 °C	Not measured	At speeds equal to or lower than 0.89 m/s, VO_2 was elevated. At speeds equal to or greater than 2.24 m/s VO_2 was not greater.
(Pohl & McNaughton, 2003)	UT	6 students	1.11 m/s and 1.94 m/s	Both thigh and waist	33 °C	Not measured	Highest VO_2 at thigh-deep exercise, followed by waist-deep, and then land.
(Hall, Grant, Blake, Taylor, & Garbutt, 2004)	UT	15 females with rheumatoid arthritis	0.69, 0.97, and 1.25 m/s	Xiphoid process	34.5 °C	For a given VO_2, RPE for legs are 15–20% greater in water	Below 0.69 m/s VO_2 was lower in water. At 1.25m/s there was no difference in VO_2.
(Hall et al., 1998)	UT	8 healthy females	0.97, 1.25, and 1.53 m/s	Xiphoid process	28 and 36 °C	Not measured	At 1.25 and 1.53 m/s VO_2 was greater in water with similar VO_2 values at 0.97 m/s.
(Rutledge et al., 2007)	UT	8 men and 8 women	2.9, 2.35, and 3.8 m/s, plus 0%, 50%, and 75% water-jet resistance	Xiphoid process	28 °C	Greater in land at only two speeds	Similar VO_2 responses for each speed until water-jets were introduced.
(Silvers, Rutledge, & Dolny, 2007)	UT	23 college runners (12 male and 11 female)	Started at own pace, increased 0.22 m/s every 4 min. Water jet resistance was constant at 40%	Xiphoid process	28 °C	No difference	No difference in peak VO_2

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Table 1 *(continued)*

Study	Mode	Sample	Speed	Depth	Temp	RPE Outcome	VO_2 Outcome
(Shono et al., 2007)	UT	6 healthy elderly women	0.33, 0.5, and 0.67 m/s (land speeds were double each water speed)	Xiphoid process	30.7 °C	Not measured	No difference at 0.5 or 0.67 m/s, VO_2 at 0.33 m/s was lower.
(Fujishima & Shimizu, 2003)	UT	9 healthy elderly men	20 min of walking at a RPE of 13	Xiphoid process	31 and 35 °C	Not measured	No difference
(Denning et al., 2010)	UT	19 adults osteoarthritis	Self selected, self selected + 0.13m/s, self selected + 0.26m/s	Xiphoid process	30 °C	No difference	No difference at fastest speed, 37% lower at self selected speed.
(Dolbow et al., 2008)	UT	13 men and 7 women	0.89m/s, 1.11m/s, and 1.33m/s	Waist level	33 °C	Greater during two fastest speeds	Greater during two fastest speeds.
(Alkurdi et al., 2010)	UT	18 females	6 speeds (0.67, 0.89, 1.12, 1.34, 1.56, 1.79 m/s)	Xiphoid process,10 cm above and below xiphoid	30 °C	No difference when water depth is 10 cm above xiphoid	No difference when water depth is 10 cm above xiphoid.
(Greene et al., 2009)	UT	57 obese or overweight adults	Treadmill speed and water jets were used to achieve 60–85% of VO_{2max}	Fourth intercostal space	Not reported	Not measured	After 12 weeks of training on a UT and land treadmill, VO_{2max} improved but was not different between modes.

Note. DWR = deep water running, SWR = shallow water running, WC = water calisthenics, and UT = underwater treadmill

Lower VO_{2max} values are not attributable to age, even though Nakanishi et al. (1999a) indicated that younger males had a lower percent decrease, 21% compared with the 27% decrease in older males. Multiple factors may contribute to lower VO_2 response during DW exercise; however, it is believed that water temperature, cardiovascular responses to hydrostatic pressure, and different muscle activity during DW exercise play some role in lowering VO_2 values (Butts et al., 1991a; Nakanishi et al., 1999b). Other factors may also include the lack of a ground support phase and different DW exercise styles.

SW Exercise. Although few studies have examined VO_2 responses during SW exercise, these studies have indicated a 16.3% (Dowzer et al., 1999) and 10% (Town & Bradley, 1991) decrease in VO_{2max} response compared with land treadmill running (Table 1). This relatively small difference between SW running and land treadmill running indicates that SW running may elicit metabolic responses similar to land treadmill running.

Dowzer et al. (1999) and Town and Bradley (1991) compared VO_2 values between SW running and DW running and indicated that VO_2 is greater during SW running than during DW running. Shallow water running VO_2 values more closely resembles land treadmill running VO_2 values. This may be because SW running involves buoyant forces and a ground support phase that are more similar to land treadmill running. Perhaps a more compelling reason for the VO_2 difference between DW running and SW running is the greater relative velocity of the water during SW. As relative velocity increases, water resistance also increases and may counteract the effects of buoyancy, i.e., greater water resistance equals greater energy expended when all else is held constant.

WC Exercise. Researchers have examined VO_2 during WC and have reported conflicting results (Table 1). Some researchers report greater VO_2 values than land-based exercise (Cassady & Nielsen, 1992; Darby & Yaekle, 2000; Johnson et al., 1977), while other researchers (Barbosa et al., 2007; Hoeger, Hopkins, & Barber, 1995) report lower VO_2 values during WC, compared with similar land exercises or land treadmill VO_{2max} tests. These contradictory results may be partially explained by the large variation in the type of calisthenics that were studied. For example, Barbosa et al. (2007) required participants to perform a "rocking horse" exercise, moving the arms and legs at the same time, while Johnson et al. (1977) examined exercises that involved the arms and legs separately. Darby and Yaekle (2000) used both leg only and arm/leg exercises separately but changed the cadence of the exercises according to the participant's heart rate. In addition, we believe that it is difficult to control for exercise intensity during WC and, depending on intensity and exercise type, WC may elicit different VO_2 responses.

UT Exercise. Oxygen consumption for UT and land treadmill exercise has been extensively studied and is highly dependent on treadmill speed and water depth. Relative to land treadmills, it is easier to control exercise intensity using underwater treadmills due the control of treadmill speed and water depth (Denning et al., 2010). Speed and depth are two vital variables when considering UT exercise. For example, Hall et al. (1998) found that when treadmill speeds were 0.97 m/s, VO_2 values were similar between aquatic and land conditions in healthy females. When speeds were 1.25 and 1.53 m/s, however, VO_2 values were greater during

UT walking compared with land treadmill walking. Another study by Hall, Grant, Blake, Taylor, and Garbutt (2004) indicated that VO_2 was significantly lower in patients with rheumatoid arthritis when speeds were lower than 0.97 m/s. In contrast, Masumoto et al. (2008) reported greater VO_2 values during 0.67 m/s walking in xiphoid deep water on UT versus land. The UT used in this study employed a water current that matched the speed of walking and likely accounted for the greater VO_2 observed during UT.

Water depth may also influence UT VO_2 values. Alkurdi et al. (2010) compared VO_2 values in females during land and UT walking at six speeds (0.67–1.78 m/s) and three water depths (xiphoid, 10 cm below, and 10 cm above xiphoid). Regardless of walking speed, VO_2 was significantly greater in the lowest water depth compared with all other conditions, while land VO_2 was similar to the 10 cm above xiphoid depth. These results demonstrate that relatively minor changes in water depth near the xiphoid process influence exercise VO_2. In support of these findings, Pohl and McNaughton (2003) reported the highest VO_2 values for UT walking and running occurred during thigh-deep water levels, followed by waist-deep water levels. Land treadmill walking and running elicited the lowest VO_2 values. At ankle and knee depths, Gleim and Nicholas (1989) reported that the lowest VO_2 values occur during land treadmill walking, with greater values at ankle depth and even greater values at the water depth just below the knee.

It would seem that as UT speed increases, water resistance elicits greater VO_2 values, and as water depth increases above the pelvis, water buoyancy produces lower VO_2 values. Whether the VO_2 response would be lower, higher, or equal to similar land-based running responses may depend on the combination of both treadmill speed and water depth. One combination that seems to produce similar VO_2 values in an arthritic population is to set the water depth to the xiphoid and to set the treadmill speed to approximately 1.04 m/s for water and land modes (Denning et al., 2010).

Heart Rate. Because HR is a component of cardiac output (i.e., stoke volume × HR) and hence VO_2, the trends in HR reported in the literature tended to follow those for VO_2 when comparing modes between environments. In comparison with measuring VO_2, however, HR is a more clinically-friendly measure and therefore a description of the HR trends for each mode between environments follows.

DW Exercise. Numerous researchers have investigated differences in HR response between DW running and land treadmill exercises. Due to the large number of studies reporting similar results, it may be concluded with some confidence that DW running elicits lower maximal heart rate (HR_{max}) values than land running. For instance, HR_{max} values during DW running are nearly 15% less than land-based running (Town & Bradley, 1991). This difference is thought to be independent of age (Chu, Rhodes, Taunton, & Martin, 2002; Nakanishi et al., 1999b) and gender (Butts et al., 1991a; Glass, Wilson, Blessing, & Miller, 1995) and has even been observed in trained runners (Butts et al., 1991b; Town & Bradley, 1991).

SW Exercise. Two studies were included in this review that reported HR during SW exercise and both reported similar decreases in HR during SW exercise when compared with land running exercise (Dowzer et al., 1999; Town & Bradley, 1991). These same researchers were also in agreement that SW exercise elicited higher HR values than DW exercise. The greater HR values observed may in part be due to the presence of a ground reaction force and the higher relative fluid velocity that occurs during SW than DW exercise.

WC Exercise. Mixed results have been reported for HR responses during WC compared with land-based exercises. Hoeger et al. (1995) reported significantly lower HR values (≈ 10 beats/min. lower) while Johnson et al. (1977) reported greater HR values, (≈ 15 beats/min. greater) during WC than land-based exercise. The differences in results are likely due to differing methods. Participants in the Johnson et al. (1977) study performed the same exercises under both conditions (water and land), whereas the Hoeger et al. (1995) study compared various water exercises to a maximal treadmill running test.

UT Exercise. As with oxygen consumption, HR responses during UT exercise depend on the treadmill speed. Hall et al. (1998) found that when treadmill speeds were 1.25 and 1.53 m/s, HR was greater during UT running compared with land treadmill running. At lower speeds (0.69 m/s and 0.97 m/s), HR was less or equal to the HR values achieved on land (Hall et al., 2004). Accordingly, UT exercise at speeds above 0.97 m/s may result in a HR that is greater than what would be produced on a land treadmill, and any speed below 0.97 m/s may elicit lower HR values. This may only be true, however, if the water is set at the xiphoid level (Gleim & Nicholas, 1989; Pohl & McNaughton, 2003). Masumoto et al. (2008) compared walking at 2.4 kph on land with walking in xiphoid-depth water on a UT with a current that matched the walking pace. HR was greater in UT vs. land; however, this was likely due to the ~48% greater VO_2 due to walking against a current. When the UT walking pace was adjusted (1.8 kph) to yield a VO_2 comparable to land-based walking, HR values were the same.

Rating of Perceived Exertion. Borg's rating of perceived exertion (RPE) is based on a subjective feeling of exertion and fatigue during exercise and is used to assess and regulate exercise intensity (see Table 1). The theoretical premise of RPE is that a person rates her/his exercise whole body exertion using a numerical value on a scale from 6 to 20 (or 1–10), representing a verbal expression of effort during exercise (Borg, 1970).

DW Exercise. There have been a variety of studies investigating RPE during various aquatic exercises, including the DW exercise (Table 1). Results of these studies revealed that during maximal effort, no differences in RPE between DW running and land-based running occur (Butts et al., 1991a; Nakanishi et al., 1999b). Matthews and Airey (2001) measured RPE at a submaximal effort using 60, 70, and 80% of heart rate reserve to which reported RPE scores were 1.4, 2.3, and 2.8 points greater during DW running, relative to land RPE.

SW Exercise. To the knowledge of the authors, no peer-reviewed research has compared RPE between SW exercise and land-based exercise.

WC Exercise. Two studies examining RPE during WC have produced mixed results (Table 1). Barbosa et al. (2007) investigated RPE at two different water depths and reported that RPE at hip depth was greater than RPE at breast depth and on land. There was no significant difference between breast depth and land exercise. Conversely, Hoeger et al. (1995) reported lower RPE levels during WC with participants immersed to the arm pits (axilla) versus land. These mixed results may be partially accounted for by the differences in the exercises performed and data collection procedures, all of which likely influenced RPE. With many varieties of WC, it is difficult to compare RPE outcomes for aquatic and land-based calisthenics.

UT Exercise. Researchers have reported that gait speed influences RPE during UT exercise. Rutledge et al. (2007) studied RPE during UT exercise at three speeds (2.9, 3.35, and 3.8 m/s) and three water jet resistance levels (0%, 50%, 75%). They reported that RPE was greater for land treadmill than UT exercise with 50% and 75% jet resistance. Hall et al. (2004) reported that at speeds greater than 0.7 m/s, RPE in the legs was greater in water than on land. Below 0.7 m/s, there was no significant difference. This contradicts Denning et al. (2010) who reported no difference for RPE for speeds greater than 0.7 m/s. This difference is likely related to how the RPE scale was directed, regionally at legs or globally at the whole body. Another likely factor is water depth. When the water level is at the xiphoid level, RPE seems to decrease. Alkurdi et al. (2010) compared RPE in females during land and UT walking at 6 speeds (0.67–1.78 m/s) and 3 water depths (xiphoid, 10 cm below and 10 cm above xiphoid). Regardless of walking speed, RPE was significantly greater in the lowest water depth compared with all other conditions, while land RPE was similar to the 10 cm above xiphoid depth. These results demonstrate that relatively minor changes in water depth can influence a person's perception of effort. Masumoto et al. (2008) compared walking at 2.4 kph on land with walking in xiphoid-depth water at the same speed on a UT with a water current resistance that matched the walking pace. Separate RPE values focusing on breathing and legs were greater in SW vs. land; however, this was likely due to the ~48% greater VO_2 due to walking against the current. When the UT walking pace was adjusted (1.8 kph) to yield a VO_2 comparable to land-based walking, RPE values were the same.

Biomechanical and Pain Responses

In this section, we discuss studies regarding biomechanical and pain responses conducted using the four aquatic modes, compared with a similar land-based mode. Stride frequency and length and pain and functional gains in special populations (i.e., rheumatoid arthritis, osteoarthritis, fibromyalgia, and lower back pain) are included (Table 2) as they are frequent biomechanical or pain response dependent variables used in this line of research.

Stride Frequency. One biomechanical dependent variable is the rate at which strides occur during exercise.

DW Exercise. Lower extremity kinematics during DW running are different from kinematics during land running (Kilding, Scott, & Mullineaux, 2007; Killgore, Wilcox, Caster, & Wood, 2006; Moening, Scheidt, Shepardson, & Davies, 1993). Studies examining stride frequency during DW exercise are presented in Table 3. Stride frequency during DW running is close to half of the stride frequency for running on land (Masumoto, Delion, & Mercer, 2009). Killgore et al. (2006) examined two different styles of DW running and observed that both styles, a scissors-type task (cross country style) and running-type task (high-knee style), elicited lower stride frequencies. The cross country style of DW running, however, was more similar to land running than the high-knee style. The lack of ground support and water resistance during DW exercise may account for the decreased stride frequency.

Table 2 Description of Studies Comparing Pain and Mobility During Different Aquatic Modes to a Similar Land-Based Mode

Study	Mode	Sample	Exercise Program	Depth	Temp	Pain	Mobility
(Minor et al., 1989)	WC	120 subjects with rheumatoid arthritis and osteoarthritis	One hour, three times a week for 12 weeks exercising at 60–80% of heart rate max	Chest level	Not reported	No difference although both groups improved	No difference although both groups improved
(Hall, Skevington, Maddison, & Chapman, 1996)	WC	139 subjects with chronic rheumatoid arthritis	30 min sessions, twice weekly for 4 weeks	Not reported	Not reported	Decreased pain level for the land mode although both groups improved	
(Jentoft et al., 2001)	WC	47 females with fibromyalgia	Twice a week for 20 weeks, exercising within 60–80% heart rate maximum	Not reported	34 °C	No difference although both groups improved	No difference although both groups improved
(Foley et al., 2003)	WC	105 subjects with osteoarthritis	30 min, three times a week for 6 weeks	Not reported	Not reported	No difference although both groups improved	No difference although both groups improved
(Sjogren et al., 1997)	WC	60 subjects with chronic low back pain	Two group sessions a week for 6 weeks	Not reported	Not reported	No difference although both groups improved	No difference although both groups improved
(Wyatt et al., 2001)	WC	46 subjects with knee osteoarthritis	Three times a week for 6 weeks	5 feet	32.2 °C	Decrease in pain level	No difference although both groups improved
(Evcik et al., 2008)	WC	63 subjects with fibromyalgia	Three times a week for 5 weeks	Not reported	33 °C	Aquatic and land groups reduced pain score by 40% and 21%, respectively	

(continued)

Table 2 *(continued)*

Study	Mode	Sample	Exercise Program	Depth	Temp	Pain	Mobility
(Green et al., 1993)	WC	47 subjects with osteoarthritis in the hip	Twice weekly for 6 weeks in pool but 18 weeks total	Not reported	Not reported	No difference although both groups improved	No difference although both groups improved
(Sylvester, 1990)	WC	14 subjects with osteoarthritis in the hip	30 min, twice a week for 6 weeks	Not reported	Not reported	No difference although both groups improved	
(Dundar, Solak, Yigit, Evcik, & Kavuncu, 2009)	WC	65 subjects with chronic low back pain	60 min, 5 times a week for 4 weeks	Shallow end of swimming pool	33 °C	No difference although both groups improved	Significantly improved
(Yozbatiran, Yildirim, & Parlak, 2004)	WC	60 subjects with chronic low back pain	3 times/ week for 4 weeks	Not reported	Not reported	No difference although both groups improved	No difference although both groups improved
(Assis et al., 2006)	DWR	60 sedentary women with fibromyalgia	60 min, three times a week for 15 weeks	Neck level	28–31 °C	No difference between groups, although both decreased pain scored by 36%	Not measured
(Melton-Rogers et al., 1996)	DWR	8 women with class II and III rheumatoid arthritis	Max test on stationary bike, DWR started at 92 beats/min increasing 6 steps every 2 min	Neck level	33 °C	No difference at peak VO_2 or at 60% of peak	Not measured
(Denning et al., 2010)	UT	19 subjects with osteoarthritis	Self selected pace, Self selected + 0.13m/s, Self selected + 0.26m/s	Xiphoid process	30 °C	Decrease in pain level	Significantly improved

Note. DWR = deep water running, SWR = shallow water running, WC = water calisthenics, and UT = underwater treadmill

Table 3 Description of Studies Comparing Stride Length and Stride Frequency During Different Aquatic Modes to a Land-Based Mode

Study	Mode	Sample	Speed	Depth	Temp	Stride Length	Stride Frequency
(Masumoto et al., 2008)	UT	9 older females	0.33, 0.5, and 0.67 m/s, land speeds were doubled	Xiphoid process	31 °C	Greater at matched speeds	Lower at all speeds
(Shono et al., 2007)	UT	8 elderly women	0.33, 0.5, and 0.67 m/s, land speeds were doubled	Xiphoid process	30.7 °C	Step length was greater at matched speeds	Lower at matched speeds.
(Shono et al., 2001)	UT	6 elderly women	0.33, 0.5, and 0.67 m/s, land speeds were doubled	Xiphoid process	30.7 °C	Not measured	Nearly half
(Kato et al., 2001)	UT	6 males	0.56 m/s, starting speed, increased by 0.56 m/s to 3.33 m/s	Waist level	29 °C	Not measured	Lower at speeds of 1.11, 2.22, 2.78, and 3.33 m/s.
(Hall et al., 2004)	UT	15 females with rheumatoid arthritis	0.69, 0.97, and 1.25 m/s	Xiphoid process	34.5 °C	Not measured	Approximately 21.9 strides/min lower at all speeds
(Hall et al., 1998)	UT	8 healthy females	0.97, 1.25, and 1.53 m/s	Xiphoid process	28 and 36 °C	Not measured	27 strides/min slower at all speeds
(Pohl & McNaughton, 2003)	UT	6 students	1.11 m/s and 1.94 m/s	Thigh and waist level	33 °C	Not measured	Similar at all conditions during walking, but 20 strides/min lower for the waist deep running.

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Table 3 *(continued)*

Study	Mode	Sample	Speed	Depth	Temp	Stride Length	Stride Frequency
(Barela & Duarte, 2008)	SWR	10 elderly (6 males, 4 females)	Self selected	Xiphoid process	Not reported	Significantly shorter	Significantly lower
(Barela et al., 2006)	SWR	10 healthy adults, (4 males, 6 females)	Self selected	Xiphoid process	Not reported	No difference	Significantly lower
(Town & Bradley, 1991)	SWR and DWR	9 trained runners (7 males, 2 females)	Increased each minute, final 2 min represented max exertion.	DWR- 2.5–4m SWR—1.3m	Not reported	Not measured	Greater turnover in SWR compared with DWR
(Killgore et al., 2006)	DWR	20 distance runners	60% of maximal treadmill VO_2	3.96m	27.2 °C	Not measured	High knee style and cross country style both significantly lower, although high knee style is more similar to land.
(Masumoto et al., 2009)	DWR	7 healthy subjects (3 males, 4 females)	RPE of 11, 13, and 15	Deep enough so no foot contact occurred	28 °C	Not measured	Increased as RPE increased, but was approximately 49% lower.
(Frangolias & Rhodes, 1995)	DWR	13 elite distance runners (8 males, 5 females)	Starting load of 500 and 750g increasing by 400 g/min. Load was added to a bucket.	Neck level	28 °C	Not measured	Significantly lower

Note. DWR = deep water running, SWR = shallow water running, WC = water calisthenics, and UT = underwater treadmill

SW Exercise. Few scientists have investigated stride frequency during SW exercise. Stride frequency is decreased in SW walking for adults and elderly individuals (Barela & Duarte, 2008; Barela et al., 2006). Town and Bradley (1991) compared stride frequency during DW and SW running and reported that stride frequency was 108.2 strides*min^{-1} during SW running and 83.9 strides*min^{-1} during DW running.

WC Exercise. To the knowledge of the authors, no peer-reviewed research has compared stride frequency between WC exercise and land-based exercise.

UT Exercise. There is limited research on the biomechanical characteristics of UT exercise (Table 3). As with DW exercise, stride frequency is nearly 50% less during UT walking than during land treadmill walking (Shono et al., 2007). Hall et al. (1998) reported a 27 strides*min^{-1} deficit during UT walking when compared with land treadmill walking in healthy females. A common finding among many UT studies is lower stride frequencies regardless of the speeds used (Benelli et al., 2004; Hall et al., 1998; Kato, Onishi, & Kitagawa, 2001). One researcher contended that the main difference in stride frequency for UT exercise occurs during running and not during walking (Pohl & McNaughton, 2003).

Stride Length. The length of a stride typically is measured as the absolute distance from one foot contact (e.g., toe or heel) to the next for the same foot.

DW Exercise. To the knowledge of the authors, no peer-reviewed research has compared stride length between DW exercise and land-based exercise. This finding may not be surprising given the lack of foot contact occurring during DW exercise.

SW Exercise. Only two studies have compared stride length differences between SW exercise and land-based exercise, and these studies are somewhat contradictory (Table 3). Barela and Duarte (2008) indicated lower stride lengths occur during SW walking with elderly individuals (approximately 70 years of age). Barela et al. (2006), however, reported no difference in stride length in healthy adults (i.e., approximately 29 years of age). This may indicate age affects stride length during SW and land-based exercise.

WC Exercise. To the knowledge of the authors, no peer-reviewed research has compared stride length between WC exercise and land-based exercise.

UT Exercise. Researchers who have studied stride or step length during UT exercise reported longer strides or steps, compared with walking on land at the same speed (Masumoto et al., 2008; Shono et al., 2007). These results are probably due to buoyant forces that cause participants to "float" for an extended period of time, similar to the gait of astronauts walking in a microgravity environment.

Due to the lower stride frequencies and the mixed reports regarding stride length, it appears that during SW and UT exercise, the principle of specificity is not met; stride frequency and stride length during aquatic exercise are not similar to land-based exercise.

Functional Gains. Even though stride frequency and stride length may be different during aquatic exercise, the therapeutic effect related to functional gains may still be positive. In reviewing studies regarding functional gains, a quantitative mobility measurement (e.g., time up & go test (TUG), 1-mile walk time, 100 m walk time) had to be present for us to include the study within our review.

DW and SW Exercise. There is a lack of research measuring functional gains after DW and SW exercise. To our knowledge, no study has compared functional gains that result from DW or SW exercise to functional gains resulting from land-based exercises.

WC Exercise. Researchers investigating the effects of WC on functional gains can be found in Table 2. Jentoft et al. (2001) tested functional gains in women with fibromyalgia with a 100 m walk time test and reported no difference in walk time between the aquatic and land-based interventions, although both groups improved. The improved walking times remained after a 6-month follow up. Similar results have been reported in subjects with chronic low back pain (Sjogren et al., 1997). Although WC does not improve functional gains more than land-based exercise, WC does appear to improve functional gains in special populations as effectively as land-based treatments. This idea is supported by researchers who used different functional gain tests to study the therapeutic effect of WC on various pathological populations (Foley et al., 2003; Green, McKenna, Redfern, & Chamberlain, 1993; Minor, Hewett, Webel, Anderson, & Kay, 1989; Wyatt, Milam, Manske, & Deere, 2001).

UT Exercise. There is a lack of research measuring functional gains after UT exercise. Denning et al. (2010), the only study found comparing functional gains after underwater and land treadmill treatment, measured functional gains using TUG scores before and after the aquatic and land interventions in individuals with osteoarthritis. TUG scores were 240% greater (i.e., time was longer) after land treatment when compared with UT treatment. This indicates a significant improvement in functional gains after UT walking.

Pain Responses. This section presents results of research examining pain responses in pathological populations (i.e., rheumatoid arthritis, osteoarthritis, fibromyalgia, and lower back pain) and does not include healthy subjects.

DW Exercise. Only two studies have examined pain during DW exercise. Both studies used a visual analog scale (graded from 0–10) and reported similar results. For example, Assis et al. (2006) reported no significant difference in pain levels between aquatic and land-based groups with an average decrease in pain of 36% for both groups. Melton-Rogers et al. (1996) reported no difference in pain levels between aquatic and land-based groups when measured at peak VO_2 and at 60% of peak VO_2.

SW Exercise. We are not aware of any studies that have investigated pain during or after SW exercise and land-based exercise.

WC Exercise. Numerous researchers have investigated the effects of WC exercise on pain for special populations (Table 2). Most researchers concluded that there is no difference in pain between the aquatic and land-based mode when measured after a training period (Foley et al., 2003; Green et al., 1993; Jentoft et al., 2001; Minor et al., 1989; Sjogren, Long, Storay, & Smith, 1997; Sylvester, 1990). Wyatt et al. (2001) and Evcik et al. (2008), however, did find a significant reduction in pain levels after aquatic treatment. Evcik et al. (2008) used a 10 cm visual analog scale and reported a 40% decrease in pain after the aquatic treatment and only a 21% decrease after the land-based treatment. Each paper regarding WC and pain reported improved pain levels after aquatic treatment, indicating WC as an adequate option to reduce pain in special populations. Clinicians should be aware, however, that this notion may not be fully supported by research, as some studies that did not compare the aquatic mode to a land-based mode found contradicting results (Lund et al., 2008; Wang, Belza, Elaine Thompson, Whitney, & Bennett, 2007). In addition, some of the studies included different modes of aquatic exercise (i.e., shallow water walking) in their training programs (Evcik, Yigit, Pusak, & Kavuncu, 2008; Minor et al., 1989; Sylvester, 1990).

UT Exercise. Denning et al. (2010), the only study investigating pain during UT treatment for participants with osteoarthritis, reported significant pain reduction after the aquatic intervention (using a 10 cm visual analog scale). No difference in pain was reported after the land-based intervention.

Summary

The purpose of this paper was to provide a descriptive literature review of some acute or chronic biophysical differences between aquatic and land-based exercise. The following key points may be drawn from our targeted review of the literature:

- Underwater treadmill exercise can elicit lower, equal, or greater values than land exercise. The variability in VO_2 and even HR between environments is most likely related to the nonlinear effect of fluid resistance with changes in treadmill speed and the unloading that occurs with changes in water depth.
- Generally, maximal effort DW exercise is capable of eliciting RPE responses that are similar to RPE responses during maximal effort land exercise.
- Stride frequency tends to be lower in all aquatic exercise modes compared with equivalent land exercise.
- Researchers tend to report no difference in pain levels during water calisthenics compared with land exercise in special populations. There is, however, a significant decrease in pain using both mediums.
- Exercising on a UT may improve functional gains (e.g., TUG) more than land treadmill exercise. It should be noted that this observation is based on only one available study suggesting there is a need for future research using this mode of aquatic exercise.

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